WIDEBAND TRANSMISSION THROUGH NARROWBAND TRANSPONDER

Field of the Invention

This invention relates to communications, and more particularly to communications of both wideband and narrowband signals over a communication path including a beamformer.

Background of the Invention

Communications are very important in the modern world. Techniques for communication include public switched telephone systems (PSTNs) operating over land lines, and also include other types of terrestrial lines, such as microwave links and fiber optic buses. The increasing use of the Internet makes wideband communications more important. For many purposes, land-line communications are not suitable, as for example for communication to or with aircraft and ships at sea. For communications with such mobile stations, conventional ship-to-shore type long-wave systems are not satisfactory, in that they tend to be very narrow-band.

Communications satellites or transponders are coming into widespread use for communications with locations which are not served by land lines. Such communications systems include satellite-based mobile telephone systems. These systems include low-earth-orbit (LEO) systems, in which the satellite constellations provide low time latency because of the proximity of the communicating satellite to the earth's surface. LEO systems have not found favor, because of the complexity of the handover of signal among satellites, and because the large number of satellites required for complete coverage and system economics necessitated inexpensive, and therefore limited-capability satellites. These limited-capability satellites, in turn, have small-aperture antennas and relatively low-power transmitters. These, in turn limit the performance, and tend to make the user terminals or handsets bulky and expensive.

Geosynchronous communications satellites have the advantage of not requiring earth stations to track the spacecraft, since its position relative to a fixed location on the earth's surface remains fixed. Fewer geosynchronous spacecraft are required to provide broad coverage, but complete earth coverage is not possible, or is at least difficult. In an inclined orbit, more coverage is possible, but tracking is required. Geosynchronous orbits are, however, distant

from the earth, and consequently require large-aperture antennas and relatively high transmitted power (EIRP) to provide reliable communications with earth stations and user terminals. Some geosynchronous systems, such as Echostar, are simple "bent-pipe" systems, in which the uplinked signal modulated onto a carrier is merely converted to a different carrier frequency and downlinked, with the change in frequency being for providing isolation between uplink and downlink. Other systems receive uplinked carrier signals modulated with digital signals representing independent information such as an individual mobile user conversation, and actually demodulate the independent signals to baseband and process the digital signals, as for example to regenerate the digital signals to obviate waveform degradation attributable to the uplink.

Improved communications systems are desired.

Summary of the Invention

A communication spacecraft provides cellular communications among a plurality of user terminals and ground stations, by way of paths having a bandwidth generally suited for audio signals, and also provides communications among at least the ground stations by way of at least one path having a bandwidth at least five times greater than the bandwidth suitable for audio signals. The spacecraft includes a

downlink antenna including a plurality of antenna elements, for receiving guided electromagnetic energy at a feed port of each of the antenna elements, and for radiating the energy in the form of unguided radiation. The spacecraft also includes an analog beamformer including a plurality of beam input ports and a plurality of elemental antenna ports, each of which is coupled to one of the antenna elements, for producing at least one independent beam of electromagnetic downlink radiation from guided energy applied to each of the beam input ports, so that plural downlink antenna beams are formed when signals are applied to a plurality of the beam input ports of the analog beamformer. A receiving arrangement receives unguided electromagnetic uplink radiation including at least one carrier, and at least transduces the unguided electromagnetic uplink radiation into guided electromagnetic energy on a plurality of separate paths. In some contexts, the receiving arrangement also downconverts the signal carrier frequency to a lower frequency or to baseband. A narrowband digital channelizer has individual channels. Each of the individual channels has a bandwidth suitable for audio signals. The channelizer includes a plurality of input ports and a plurality of output ports. At least some of the input ports of the digital channelizer are coupled by way of corresponding ones of the

plurality of separate paths to the receiving arrangement. The digital channelizer receives the guided electromagnetic energy from a plurality of the separate paths, and extracts each of the independent narrowband signals from at least one carrier, to thereby produce separated independent narrowband signals on the plurality of output ports of the digital channelizer. A wideband channelizer has an individual channel bandwidth at least five times greater than that of an individual channel of the narrowband channelizer. The wideband channelizer is coupled to at least a portion of the receiving arrangement, for extracting at least one wideband signal from the carrier, to thereby produce separated independent wideband signals. A switching arrangement is coupled to the plurality of output ports of the narrowband channelizer and is also coupled to the wideband channelizer. The switching arrangement receives the independent narrowband signals and the wideband signals, and groups together those signals associated with each of the plural downlink antenna beams, to thereby produce combined signals grouped by beam. The combined signals grouped by beam may include any number of the wideband signals, including the number zero. Lastly, the spacecraft also includes a coupling arrangement coupled to the switching arrangement and to the corresponding beam input ports of the beamformer. This causes the

beamformer and the downlink antenna to route each of the combined signals to the antenna beam for which it is destined.

A method according to another aspect of the invention is for transmitting wideband signals and at least some of a plurality of independent signals through an analog beamformer. Each of the independent signals has a bandwidth no greater than one-fifth of that of the wideband signals. The method includes the step of receiving unguided electromagnetic radiation including (a) a plurality of the independent signals having bandwidths suitable for audio use and (b) the wideband signals, to thereby produce guided electromagnetic energy signals representing combined wideband signals and narrowband independent channels. In one mode of this method, the plurality of independent signals is modulated onto a subcarrier which is, in turn, modulated onto a carrier. The method according to the aspect of the invention further includes the steps of channelizing the signals representing combined wideband signals and narrowband independent channels, to thereby extract separated independent narrowband signals, and of separately channelizing the signals representing combined wideband signals and narrowband independent channels, to thereby extract separated wideband signals. Those of the separated independent narrowband signals and the separated wideband signals which are

associated or destined for transmission over the same antenna beam are combined so as to produce antenna beam signals. The antenna beam signals are beamformed to produce plural antenna element guided wave signals which, when combined "in space" produce the desired beams. The last step of the method according to this mode of the method is to couple each of the antenna element guided wave signals to the guided wave input port of one of the antenna elements of an antenna array, so that each one of the antenna element receives one, and only one, of the antenna element guided wave signals. In a particularly advantageous mode of the method according to the invention, the step of channelizing the signals representing combined wideband signals and narrowband independent channels includes the step of digitally channelizing the combined wideband and narrowband independent channels. In a further advantageous mode of the inventive method, the step of channelizing includes the step of limiting the bandwidth of each of the independent signals to a bandwidth suitable for carrying of intelligible audio, which in one version is a bandwidth of less than about 10 Khz.

Brief Description of the Drawing

FIGURE 1 is a simplified block diagram of a portion of a spacecraft including portions of the forward communication system;

FIGURE 2 is a simplified block

diagram of a wideband portion of the structure of FIGURE 1;

FIGURE 3 is a simplified diagram of a spacecraft-based communication system in which the invention may be used;

FIGURE 4 is a simplified block diagram of a portion of a spacecraft including portions of the reverse communication system; and

FIGURE 5 is a simplified block diagram of a wideband portion of the structure of FIGURE 4.

Description of the Invention

FIGURE 3 is a simplified block diagram of a spacecraft communication system 8. In FIGURE 3, a spacecraft 10 includes an uplink antenna 12 and a downlink antenna 30. On the surface 300 of the Earth, a ground station 310 includes an antenna 310A by which ground station 310 communicates with the spacecraft 10. Also illustrated are a plurality of mobile user terminals (UT) illustrated together as 312. User terminals 312 communicate with other user terminals and with the ground station 310 by using the satellite's communication system 11 as a transponder.

In FIGURE 1, a forward portion 11F of a spacecraft communication system 11 includes a set of antennas designated as 12, including antennas 12_a, 12_b, . . ., 12_f. Antenna set 12 represents a set of uplink antennas on a

spacecraft for receiving uplinked signals, as from an earth station. Antenna set 12 may be, for example, a high-gain antenna reflector pointed at an earth station or gateway in the context of a mobile station communications system, with individual feed antenna elements 12_a, 12_b, . . ., 12_f. Uplinked signals are received by the antennas of set 12. More particularly, in the ACeS system, for example, the uplink signal includes plural C-band carriers, and each of the C-band carriers has a bandwidth of about 300 MHz, and is modulated with subcarriers spaced by a bandwidth. In the context of an ACeS system, the subcarrier spacing is about 200 KHz. Each subcarrier, in turn, may be modulated with a number of information signals, such as eight full-rate independent audio information signals (full rate meaning one time-division-multiplex (TDM) burst each frame) or thirty-two quarter-rate independent audio information signals (where quarter-rate means one TDM burst every four frames). In the case of ACeS, the independent TDM signals include cellular telephone signals. Each of the plural (eight or thirty-two) independent signals occupies the 200 KHz bandwidth of its subcarrier exclusively during its portion of the TDM interval or slot.

The signals received by each antenna of set 12 of FIGURE 1 are applied to an associated C-band receiver of a set 14. More specifically, antenna 12_a is coupled to a C-band

receiver (RCVR) 14_a and its associated local oscillator (LO) 16_a, antenna 12_b is coupled to a C-band receiver (RCVR) 14_b and its associated local oscillator (LO) 16_b, . . ., and antenna 12_F is coupled to a C-band receiver (RCVR) 14_F and its associated local oscillator (LO) 16_F. Each C-band receiver 14_a, 14_b, . . ., 14_F of set 14 is an analog processing device which filters the received signals to reduce undesired out-of-band signals, and also receives intermediate-frequency (IF) signals from an associated synthesized or otherwise stable local oscillator of a set 16 of local oscillators. More particularly, a local oscillator 16_a is associated with receiver 14_a, a local oscillator 16_b is associated with receiver 14_b, . . ., and a local oscillator 16_F is associated with receiver 14_F. Thus, there is, in principle, one receiver of set 14 for each antenna of set 12; the need for redundancy of active devices may, however, require additional or supernumerary receivers, and additional switching (not illustrated) for switching among the receivers. Each receiver of set 14 has an instantaneous bandwidth of about 30 MHz, may be tuned across the 300 MHz bandwidth of a C-band carrier, so as to allow any one of the receivers of set 14 to access any one signal, or any group of frequency-adjacent signals having a combined bandwidth of less than about 30 MHz. This tuning may be effectuated for any receiver of set 14 by

tuning the IF signals from its associated local oscillator of set. Thus, the output bandwidth of any C-band receiver 14 represents any desired 30 MHz portion of the 300 MHz C-band bandwidth. Each receiver of set 14 downconverts its selected 30 MHz band to an intermediate frequency (IF). In the case of ACeS, the intermediate frequency is around 400 MHz.

The downconverted 30 MHz band associated with any particular receiver 14_a, 14_b, . . ., 14_F of set 14 is applied to a corresponding analog forward link downconverter. More particularly, the downconverted 30 MHz band of signals from receiver 14_a of FIGURE 1 is applied to an analog forward link downconverter (FLD) block 18_1, which represents downconversion from the IF frequency to baseband, the downconverted 30 MHz band of signals from receiver 14_b of FIGURE 1 is applied to an analog forward link downconverter (FLD) block 18_2, which represents downconversion from the IF frequency to baseband, . . ., and the downconverted 30 MHz band of signals from receiver 14_F is applied to an analog forward link downconverter block 18_F. It should be understood that the number of FLD blocks equals the number of C-band receiver blocks in principle, but again the requirements for reliability redundancy may require more of one than of the other. Thus, each receiver of set 14 of receivers produces output signal having a

bandwidth no greater than about 30 MHz, modulated onto an intermediate-frequency (IF) carrier. The signals produced at the output ports of the C-band receivers of set 14 are ultimately coupled to a block 20, which represents a digital channelizer. Because it is easier at the current state of the art to make a digital channelizer which operates at baseband rather than at an IF frequency, it is desirable to downconvert each of the IF-based signals, as produced by the C-band receivers of set 14, to baseband. Conversion to baseband of the IF-frequency signals produced at the output of each C-band receiver of set 14 is performed by a corresponding one of the forward link downconverters (FLDs) of a set 18. More particularly, a forward link downconverter 18_1 is associated with C-band receiver 14_a, a forward link downconverter 18_2 is associated with C-band receiver 14_b, . . ., and a forward link downconverter 18_F is associated with C-band receiver 14_F. The only reason for the use of the set 18 of FLDs, then, is due to the economics of fabrication of the digital channelizer 20, and the combination of the downconverters of set 18 and the digital channelizer 20 may be considered to be simply a digital channelizer 21, since there is no requirement in principle for downconversion to baseband. As illustrated in FIGURE 1, channelizer 20 has FLDs of set 18 coupled to its input ports $20i_1$ through $20i_N$. More

particularly, channelizer 20 has its input port $20i_1$ coupled to receive signal from FLD 18_1, its input port $20i_2$ coupled to receive signal from FLD 18_2, . . ., and its input port $20i_N$ coupled to receive signal from FLD 18_N. Channelizer 20 has about 140 active output ports in the ACeS version, and additional ports for redundancy/reliability and for additional capacity under certain circumstances. Thus, channelized digital signals are available at each of the output ports $20o_1$, $20o_2$, . . ., $20o_{140}$ of channelizer 20, regardless of whether FLDs are used or not. The digital signals produced at each output port $20o_1$, $20o_2$, . . ., $20o_{140}$ of channelizer 20 are in the form of digital signals modulated onto a baseband carrier, and each such modulated baseband carrier represents a plurality of independent digital signals, with each independent signal representing, for example, voice signal travelling in one direction to or from a mobile user terminal on the ground. In practice, channelizer 20 has an ultimate bandwidth of about 9 MHz per beam output port, which translates to about 45 subcarriers, corresponding to a maximum of 280 full-rate audio channels, or about a thousand quarter-rate audio channels per output port. It should be noted that each active output port $20o_1$, $20o_2$, . . ., $20o_{140}$ represents one antenna beam, so if, as in the case of ACeS, there are 140 outputs from the digital channelizer, 140

separate antenna beams are intended.

The output ports of channelizer 20 of FIGURE 1 are coupled to a switch matrix illustrated as 22. Switch matrix 22 is a digitally-controlled analog-signal-handling device, which couples the digital-modulated-onto-carrier signals from each output port $20o_1$, $20o_2$, . . ., $20o_{140}$ of channelizer 20 to one of a set 24 of active forward link upconverters (FLUs), which are designated 24_a, 24_b, . . ., 24_{140}. The ACeS spacecraft uses about 140 active FLUs, and has a total of about 180 FLUs, with the inactive FLUs being spares for redundancy. Each FLU 24_a, 24_b, . . ., 24_{140} of set 24, with the aid of an associated local oscillator (LO), upconverts the digital-modulated-onto-carrier combined independent signals applied thereto from an output port of channelizer 20. The frequency upconversion is to a downlink frequency, which in the case of ACeS happens to be at about 1500 MHz. The resulting upconverted signals (at a downlink frequency) produced at the output of each FLU of set 24 are coupled from the FLU to a corresponding input port of a switch combining matrix (SCM) 26. SCM 26 has a total of about 180 input ports, and about 140 output ports. Each of the 140 output ports of SCM 26 is coupled by way of a path of a coupling arrangement 27 to one of the beam input ports $28i_1$, $28i_2$, . . ., $28i_{140}$ of a beamformer 28. More particularly, output port $26o_1$ of SCM 26 is

coupled by way of signal path 27_1 to input port $28i_1$ of beamformer 28, output port $26o_2$ of SCM 26 is coupled by way of signal path 27_2 to input port $28i_2$ of beamformer 28, . . ., and output port $26o_{140}$ of SCM 26 is coupled by way of signal path 27_{140} to input port $28i_{140}$ of beamformer 28. SCM 26 is basically a switch matrix which allows the signals from any combination of 140 active FLUs to be coupled to a beam input port of beamformer 28, and which also allows the output signals of two or more FLUs to be coupled (through hybrids) to a single beam input port of the beamformer. The switching function allows failed FLUs to be replaced by functional FLUs, and the switching-plus-combining function also allows for additional functionality of increasing the beam capacity under circumstances where a particular antenna beam experiences particularly high traffic during a period of time. For purposes of understanding the principles of the invention, SCM 26 may be ignored.

In general, the signals from each FLU 24_a, 24_b, . . ., 24_{140} of set 24 are applied to one corresponding beam input port 28_1, 28_2, . . ., 28_{140} of beamformer 28. As known to those skilled in the art, the beamformer couples the signals applied to each beam input port 28_1, 28_2, . . ., 28_{140} to the guided-electromagnetic-wave input ports $30i_a$, $30i_b$, . . ., $30i_M$ those antenna elements 30_a, 30_b, . . ., 30_M of antenna set 30 as necessary to form an antenna beam of

the desired type and shape. In the ACeS system, there are about 140 spot beams. The independent signals destined for each beam are coupled from the beam input port of beamformer 28 to the corresponding downlink antenna beam, and in general not to the other beams.

As so far described, the structure of system 10 of FIGURE 1 is a part of a system designated RHC, which stands for Right-Hand-Circular. This designation refers to the polarization of the uplink antenna set 12. As known to those skilled in the art, another set 112 of antennas, similar to set 12, but of the other hand of polarization, may be used in conjunction with set 12. This other hand of polarization is termed left-hand-circular (LHC). In principle, it is possible to use the same uplink frequencies with the other hand of orthogonal polarization in order to re-use the frequency band. Thus, independent signals can in principle be received by the set of antennas designated 112 in the LHC section of the system 10. Each antenna 112_a through 112_F of set 112 is coupled to a corresponding C-band receiver 114_a, . . ., 114_o of a set 114 of C-band receivers. As in the case of the RHC portion of the system, the C-band receivers are coupled to FLDs 118_1, . . ., 118_o of a set 118 of FLDs. The outputs of the FLDs of set 118 are applied individually to the input ports $20i_a$, . . ., $20i_o$ of digital channelizer 20. The various C-band receivers of set 114 and FLDs of set 118

perform in a manner equivalent to those of sets 14 and 18, with the only difference being in the signals handled, as the antennas of set 112 are capable of receiving signals of a different set from those received by antenna set 12.

According to an aspect of the invention, one or more wideband transmission paths is provided between the C-band receivers 14a, 14b, . . ., 14N of set 14 and beamformer 28, so that wideband signals, such as Internet signals, can flow through the spacecraft portion of the communications link. More particularly, the wideband transmission path bypasses the narrowband part of the spacecraft communications channel, which is the digital channelizer 20. Since, as mentioned, the channelizer may be viewed as including the associated FLDs of set 18, the wideband transmission path can also be routed around or bypass the FLDs. In the arrangement of FIGURE 1, a forward-direction wideband augmentation equipment (FWAE) 32 is illustrated as providing a path which bypasses FLD 18_1 and digital channelizer 20. More particularly, the signal path between C-band receiver 14_a and FLD 18_1 is illustrated as including a power splitter or signal bypass 17. FWAE 32 is illustrated as having it input port 32i coupled by way of a signal path 17p to an output port of splitter 17, for receiving a sample of the signal received by C-band receiver 14_a. FWAE 32 processes the signal sample by at least

downconverting the signal, with the aid of its own LO, to a frequency corresponding to that at the outputs $20o_1$, $20o_2$, . . ., $20o_{140}$. The frequency-converted wideband signals produced at the output of FWAE 32 are coupled by way of a signal path 32p to an input of switch matrix 22, where the signals can be processed in a wideband manner. All locations downstream from switch matrix 22, namely the FLU set 24, the SCM 26, and the beamformer 28, are capable of wideband operation, so a path is provided by which broadband signals can be processed through a spacecraft fitted for mobile user terminal communications. This, in turn, allows a spacecraft fitted for mobile user terminal communications, which are ordinarily narrow-band, to handle wideband signals such as Internet communications.

The invention is not limited to providing a single wideband forward signal path through the spacecraft. As illustrated in FIGURE 1, a further signal sampler 117 is illustrated as being coupled to the signal path extending between C-band receiver 114_o and FLD 118_o. The sampled signal is illustrated as being coupled to a further forward wideband augmentation equipment 132, which processes the signals in its path in the same manner as those processed in FWAE 32, and applies the wideband signals so processed to another input port of switch matrix 22. In a similar manner, other FWAEs, such as 32', can be coupled to other

signal samplers, such as 17', and to other input ports of switch matrix 22. It should be understood that, in general, wideband signals and narrowband signals should not appear at the same frequencies at the outputs of the various C-band receivers, but that, if such should occur, the signals in the overlap bands may be required not to appear in the same beams, as their presence in the same beams may be associated with different group delays and phases, and as such may interfere.

FIGURE 2 is a simplified block diagram of one possible implementation of forward wideband augmentation equipment 32. In FIGURE 2, elements corresponding to those of FIGURE 1 are designated by the same reference numerals. In FIGURE 2, the wideband RHC polarization, downconverted signal samples of the signal produced by C-band receiver 14_a of FIGURE 1 are coupled over signal path 17p to FWAE 32. Within FWAE 32, the signals are applied in common or in parallel to a bank 232 of filters. While the number of filters may be almost arbitrarily selected, the illustrated arrangement includes three filters $232_{0.5}$, $232_{1.0}$, and $232_{2.0}$, which have passbands with a width of 0.5, 1.0, and 2.0 MHz, respectively. Such filters are well known in the art, and require no further explanation. Because of their light weight, surface-acoustic-wave (SAW) filters are particularly advantageous for spacecraft use. Wideband signals with various bandwidths are

available at the output ports of the filters of filter bank 232. The variously filtered signals are applied to a switch bank 210, illustrated as containing a bank of controllable switches, which allow the signals from one or more of the filters $232_{0.5}$, $232_{1.0}$, and $232_{2.0}$ to be coupled to an input port 212i of a downconverter 212. The filter passbands can be so arranged that the total bandwidth of the filter bank can be summed. For example, when filter $232_{0.5}$ (which has a bandwidth of 0.5 MHz) is connected to the 212 downconverter via the 210 switch concurrently with filter $232_{1.0}$ (which has a bandwidth of 1.0 MHz), the total effective bandwidth of the filtering applied to the input of the 212 downconverter is the sum of 0.5 MHz and 1.0 MHz, or 1.5 Hz. The downconverter downconverts the selected wideband signal and makes it available on signal path 32p for application to an input port of switch matrix 22 of FIGURE 1. The wideband signal is then propagated, together with narrowband signals from digital channelizer 20, through wideband portions of the structure of FIGURE 1, including the switch matrix 22, FLU bank or set 24, SCM 26, and beamformer 28. Thus, the wideband signals can be routed to any of the antenna beams, just as the narrowband signals are routed.

FIGURE 4 is a simplified block diagram of a return or reverse portion 11R of the spacecraft 10 communication system. In

FIGURE 4, elements corresponding to those of FIGURE 1 are designated by like reference numbers, and elements which are similar but not identical may be designated by the same reference numerals in the 400 series. In FIGURE 4, an uplink receive antenna 430 receives uplink signals which may include both wideband and narrowband portions, but which are at L-band. The beamformer 428 is similar to beamformer 28 of FIGURE 1, but is a separate and different unit because the antennas 30, 430 and the operating frequencies are different. The beamformer 428 forms the beams as described in conjunction with beamformer 28, and produces at its output port set 428o groups of signals representing the uplinked signals on each beam. These beam-grouped signals are applied to a switch combining matrix 426, which operates at a different frequency than does matrix 26 of FIGURE 1. Switch combining matrix 426 performs redundancy switching of the return or reverse link downconverters (RLDs) of set 424 of RLDs. It also provides for channel capacity augmentation by routing or distributing "excess" signals in one uplink beam to or among the channelizer inputs. The return link downconverters of set 424 couple baseband signals, separated or maintained independent by the TDM switching, to the switch matrix 22, which can be identical to that of FIGURE 1 because both operate at baseband. While it can be identical, it cannot be the self-same unit,

because the routing of the signals in the forward direction is not the same as the routing in the reverse direction. The structure of switch matrix 22 is wideband, so there is no particular reason that wideband signals could not be routed to the input ports of channelizer, nor is there any reason that narrowband signals could not be routed to path 32p, although this would be undesirable, as the wideband signals if applied to a channelizer input port would be rendered narrowband and likely useless, and narrowband signals if applied to the wideband signal paths would not take advantage of the available bandwidth. Ordinarily, the narrowband signals will be routed to the input ports $20i_1$, $20i_2$, . . ., $20i_{140}$ of channelizer 20, and the wideband signals, if any are present, will be routed to the wideband augmentation equipment 432. In general, digital channelizer 20 of FIGURES 1 and 4 operate at baseband, and so can be structurally identical (although the self-same units cannot be used because the routing of signals in the forward and reverse directions differs). The wideband augmentation equipment 432 is similar, but not identical to, the corresponding equipment 32 of FIGURE 1. The major difference between the two wideband augmentation equipments is that the forward-direction wideband augmentation equipment 32 receives input signals at about 400 MHz for proper operation of the SAW filters, and then

downconverts to baseband, while the reverse-direction wideband augmentation equipment 432 of FIGURE 4 receives baseband signals, and must upconvert the baseband signals to a range suitable for operation of the SAW filters.

Channelizer 20 of FIGURE 4 produces narrowband signals destined for RHCP transmissions on a set $20o_1$, $20o$, . . ., $20o_N$, which are grouped by gateway destination, are routed through a set 418 of return link upconverters (RLU), for conversion to an IF frequency in the range of 400 MHz. The upconverted signals at the outputs of RLUs of set 418 are applied to C-band transmitters of a set 414, which upconvert the IF signals to the C-band downlink frequencies, in the vicinity of 3.4 GHz. The transmit signals are applied from the C-band transmitters to the antenna elements of an antenna 412 which is different from antenna 12 of FIGURE 1 because of operating frequencies, but is functionally identical.

Similarly, the narrowband output signals destined for the LHCP downlink are produced at output ports $20o_a$, . . ., $20o_o$ of channelizer 20 of FIGURE 1, and are coupled to their respective reverse link upconverters of set 418, thence to the corresponding C-band transmitters of set 414 and on to the RHCP antennas. The wideband signals coupled through return wideband augmentation equipment 432 is applied through a signal sampler or directional coupler 17, which is identical to that of

FIGURE 1, to thereby couple the wideband signals to one of the C-band transmitters. The simplified illustration allows the wideband signals to be transmitted to only a few of the ground stations, but in an actual unit, a switch matrix might be used to route the wideband signals to any of the C-band transmitters of set 14, or a plurality of return wideband augmentation equipments corresponding to 432 could be provided, together with a signal sampler or directional coupler corresponding to 17 providing access to each of the C-band transmitters of set 414. Also in FIGURE 4, switch matrix 22 couples wideband signals to additional return wideband augmentation equipments 432 and 432'', which operate much like equipment 432, and which couple their wideband output signals to signal samplers or directional couplers 17' and 117, respectively.

FIGURE 5 is a simplified block diagram illustrating details of return wideband augmentation equipment 432 of FIGURE 4. In FIGURE 5, the wideband baseband signal from switch matrix 22 of FIGURE 4 is applied over signal path 32P to an upconverter 512 of return wideband augmentation equipment 432. Upconverter 512 upconverts the signal to a frequency in the range of about 400 MHz, which is suitable for operation of SAW filters. The upconverted wideband return signal is applied to a common portion of a switch matrix

illustrated as 510, which selects one of a plurality of possible signal paths for the upconverted return signal from upconverter 512. Each path selectable by switch matrix 510 leads to a SAW filter. As in the case of FIGURE 2, the SAW filters are designated $232_{0.5}$, $232_{1.0}$, and $232_{2.0}$, which have passbands with a width of 0.5, 1.0, and 2.0 MHz, respectively. The return signal, filtered by the selected one or more of SAW filters $232_{0.5}$, $232_{1.0}$, and $232_{2.0}$, is coupled by way of signal path 432' to signal sampler or directional coupler 17 of FIGURE 4. The filter passbands are so arranged that the total bandwidth of the filter bank can be summed. For example, when filter $232_{0.5}$ (which has a bandwidth of 0.5 MHz) is connected to the 512 upconverter via the 510 switch concurrently with filter $232_{1.0}$ (which has a bandwidth of 1.0 MHz), the total effective bandwidth of the filtering available at the output of the 512 upconverter is the sum of 0.5 MHz and 1.0 MHz, or 1.5 MHz. The other return wideband augmentation equipments of FIGURE 4 are similar to return wideband augmentation equipment 432.

It is worth noting that an "antenna" as used herein refers to a transducer which transduces electromagnetic energy or power bidirectionally (in either direction) between unguided or free-space propagation and guided propagation in a transmission line. An antenna is a reciprocal device, which operates in the same manner in both transmission and reception

modes of operation. For historical reasons, some of the terms used in antenna practice are not as descriptive as might be desirable. For example, the guided-wave port of an antenna is often called a "feed" port, regardless of whether the antenna is operated in a transmitting or receiving mode. Similarly, an antenna "beam" is relatively easy to understand conceptually when the antenna is operated in a transmitting mode, but the amplitude-versus-angle characteristics of an antenna operating in the receive mode are the same as those of an antenna in the transmitting mode, and so the term "beam" is also associated with a receiving antenna, even though there is no conceptual beam involved. Those skilled in the antenna arts also realize that an antenna never exhibits perfect polarization purity, in that an antenna which is nominally RHC will respond to LHC signals, and vice versa, a "vertically" polarized signal need not be vertical in orientation nor "horizontally" polarized horizontal, and a linearly polarized antenna responds strongly to circularly polarized signals and vice versa.

The use of the term "between" as used in the description of antenna usage, and as used in electrical parlance, is different from the dictionary usage, and in no wise relates to physical location. Generally, the word "between" as used in electrical applications means that the origin of the signal or

electrical fields is one of the stated locations or blocks, and the sink or destination of the signal (or fields) is the other one of the stated locations or blocks. The route taken by the signals (or fields) in flowing from source to destination is irrelevant in the electrical context. A similar distinction must be made for electrical usage for the term "parallel," which does not have to do with physical parallelism. Rather, "parallel" in an electrical context refers to the number or existence of multiple paths extending "between" a source and destination.

While switch symbols representing mechanical switch elements have been illustrated, those skilled in the art know that these are merely symbolic or conventional representations, and that in actual practice, mechanical switches are seldom used. Instead, the symbols represent the switching function rather than the device, and the switching function is ordinarily accomplished by semiconductor or solid-state switches, often remotely controllable or controlled.

Other embodiments of the invention will be apparent to those skilled in the art. While the particular described embodiment represents an ACeS system, the frequencies and bandwidths may be widely varied from the examples. For example, while the described system is at C-band, those skilled in the art will recognize that the invention is applicable

to other frequency bands, including L, X, and K bands. Similarly, the various bandwidths of 300 MHZ, 30 MHz, 200 KHz, and the like may be almost arbitrarily selected, depending upon the characteristics of the system and of the signals being carried. While the antenna sets 12, 112 of FIGURE 1 have been described as the feed antennas of a high-gain reflector element, they may also be viewed as the output ports of the beamformer of a receive antenna array making a single beam or multiple beams. While the described transponder is in a spacecraft, the transponder could as well be terrestrial. While the routing of the various narrowband and wideband signals has been described in FIGURE 1 as being to an antenna beam, those skilled in the art know that a given signal may be routed to more than one antenna beam, and one or more signals may be routed in a "broadcast" mode so that they are transmitted over all the available antenna beams. While SAW filters have been described, other types of filters can be used if desired.

Thus, a communication spacecraft (10) provides cellular communications among a plurality of user terminals (312) and ground stations (310), by way of paths having a bandwidth generally suited for audio signals, and also provides communications among at least the ground stations (310) by way of at least one path having a bandwidth at least five times greater than the bandwidth suitable for audio

signals. The spacecraft (10) comprises a downlink antenna (30) including a plurality of antenna elements (30_a, 30_b, . . ., 30_M), for receiving guided electromagnetic energy at a feed port ($30i_a$, $30i_b$, . . ., $30i_M$) of each of the antenna elements (30_a, 30_b, . . ., 30_M), and for radiating the energy in the form of unguided radiation. The spacecraft also includes an analog beamformer (28) including a plurality of beam input ports ($28i_1$, $28i_2$, . . ., $28i_{140}$) and a plurality of elemental antenna ports, each of which is coupled (by way of a corresponding antenna element feed port $30i_a$, $30i_b$, . . ., $30i_M$) to one of the antenna elements (30_a, 30_b, . . ., 30_M), for producing at least one independent beam of electromagnetic downlink radiation from guided energy applied to each of the beam input ports ($30i_a$, $30i_b$, . . ., $30i_M$), so that plural downlink antenna beams are formed when signals are applied to a plurality of the beam input ports ($28i_1$, $28i_2$, . . ., $28i_{140}$) of the analog beamformer (28). A receiving arrangement (12,14) receives unguided electromagnetic uplink radiation including at least one carrier, and at least transduces the unguided electromagnetic uplink radiation into guided electromagnetic energy on a plurality of separate paths (15_a, 15_b, . . ., 15_F). In some contexts, the receiving arrangement (12, 14) also downconverts the signal carrier frequency to a lower frequency or to baseband. A

narrowband digital channelizer (18,20; 20) has individual channels. Each of the individual channels has a bandwidth suitable for audio signals. The channelizer (18,20;20) includes a plurality of input ports ($18i_1$, $18i_2$, . . ., $18i_N$; $20i_1$, $20i_2$, . . ., $20i_N$, $20i_a$, . . ., $20i_o$) and a plurality of output ports ($20o_1$, $20o_2$, . . ., $20o_{140}$). At least some ($18i_1$, $18i_2$, . . ., $18i_N$; $20i_1$, $20i_2$, . . ., $20i_N$) of the input ports ($18i_1$, $18i_2$, . . ., $18i_N$; $20i_1$, $20i_2$, . . ., $20i_N$, $20i_a$, . . ., $20i_o$) of the digital channelizer (20) are coupled by way of corresponding ones of the plurality of separate paths (15_a, 15_b, . . ., 15_F) to the receiving arrangement (12,14). The digital channelizer (20 receives the guided electromagnetic energy from a plurality of the separate paths (15_a, 15_b, . . ., 15_F), and extracts each of the independent narrowband signals from the at least one carrier, to thereby produce separated independent narrowband signals on the plurality of output ports ($20o_1$, $20o_2$, . . ., $20o_{140}$) of the digital channelizer (20). A wideband channelizer (32) has an individual channel bandwidth at least five times greater than that of an individual channel of the narrowband channelizer (20). The wideband channelizer (32) is coupled to at least a portion (14_a) of the receiving arrangement (12,14), for extracting at least one wideband signal from the carrier, to thereby produce separated independent wideband signals. A switching arrangement (26) is

coupled to the plurality of output ports ($20o_1$, $20o_2$, . . ., $20o_{140}$) of the narrowband channelizer (20) and is also coupled to the wideband channelizer (32). The switching arrangement (26) receives the independent narrowband signals and the wideband signals, and groups together those signals associated with each of the plural downlink antenna beams, to thereby produce combined signals grouped by beam. The combined signals grouped by beam may include any number of the wideband signals, including the number zero. Lastly, the spacecraft (10) also includes a coupling arrangement (27) coupled to the (output ports of the) switching arrangement (26) and to the corresponding beam input ports of the beamformer (28). This causes the beamformer and the downlink antenna to route each of the combined signals to the antenna beam for which it is destined.

A method according to another aspect of the invention is for transmitting wideband signals and at least some of a plurality of independent signals through an analog beamformer (28). Each of the independent signals has a bandwidth no greater than one-fifth of that of the wideband signals. The method includes the step of

receiving (at receivers of set 14) unguided electromagnetic radiation including (a) a plurality of the independent signals having bandwidths suitable for audio use and (b) the

wideband signals, to thereby produce guided electromagnetic energy signals (on set 15 of paths) representing combined wideband signals and narrowband independent channels. In one mode of this method, the plurality of independent signals is modulated onto a subcarrier (200 Khz separation in the example) which is, in turn, modulated onto a carrier (one of plural C-band carriers). The method according to the aspect of the invention further includes the steps of channelizing (20) the signals representing combined wideband signals and narrowband independent channels, to thereby extract separated independent narrowband signals, and of separately channelizing (32) the signals representing combined wideband signals and narrowband independent channels, to thereby extract separated wideband signals. Those of the separated independent narrowband signals and the separated wideband signals which are associated or destined for transmission over the same antenna beam are combined (26) so as to produce antenna beam signals. The antenna beam signals are beamformed (28) to produce plural antenna element guided wave signals which, when combined "in space" produce the desired beams. The last step of the method according to this mode of the method is to couple each of the antenna element guided wave signals to the guided wave input port of one of the antenna elements of an antenna array (30),

so that each one of the antenna element receives one, and only one, of the antenna element guided wave signals. In a particularly advantageous mode of the method according to the invention, the step of channelizing the signals representing combined wideband signals and narrowband independent channels includes the step of digitally channelizing the combined wideband and narrowband independent channels. In a further advantageous mode of the inventive method, the step of channelizing includes the step of limiting the bandwidth of each of the independent signals to a bandwidth suitable for carrying of intelligible audio, which in one version is a bandwidth of less than about 10Khz.